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Assessing the Operational Impact of New Network Centric Technology, Collaborative Replanning with User Defined Operational Picture: A Controlled Experiment with Warfighters (DRAFT I-131)

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Abstract

In adapting C2 to the 21st century we plan to conduct a controlled Human-In- The- Loop (HITL) experiment with new Network Centric Warfare (NCW) technology which will be introduced to sixteen experienced warfighters in the form of a collaborative User Defined Operational Picture (UDOP) with SORTS Force Readiness and intelligence data access enabled by an IP wide area network as a possible improvement over their use of current baseline technology in the form of the GCCS with Common Operational Picture (COP) capability. We examine here the general methodology of using controlled HITL experiments employing combat scenarios as a means of testing and evolving more effective C2 technology for the warfighter. (See the Award-winning *TTCP GUIDEx*, 2006)

In addition, we hypothesize that the results of this particular experiment will show significant improvements on the NCW performance metrics of Situational Awareness, Shared Situational Awareness and bottom-line Combat Effectiveness due to use of the new NECC(Net-Enabled Command Capability) technology employed in the experiment trials. The important role of enhanced operational replanning quality, and speed, enabled by the new technology, will be carefully examined here, since recent experimentation results strongly suggest them as NCW metrics that warrant more scrutiny by the research community. (See Hiniker & Entin, 2006). Thus we expect that collaboration and synchronized replanning will play important roles impacting combat effectiveness in this C2 experiment. As in our prior published experiments, we use a within- subjects design while employing multiple analysis of variance (MANOVA) in the statistical testing of our hypotheses. We intend to conduct the actual experiment trials during late April/May of 2007.

Introduction

Net Centric Warfare (NCW) has been defined as an information superiority-enabled concept of operations that generates increased combat power by networking sensors, decision makers, and shooters to achieve shared awareness, increased speed of command, higher tempo of operations, greater lethality, increased survivability, and degree of self - synchronization. (Alberts, Garstka, and Stein (2000)) Situational Awareness (SA), as well as its sharing by linked warfighters (SSA), is thus deemed to be a major causative factor in increasing combat power. (Hiniker & Entin, 1990, 1992: Perry, et al, 2004; Hiniker, 2005; Hiniker & Entin, 2006) Increased Speed of Command, and the associated increased speed and quality of planning, have recently received some empirical support as NCW contributors to combat effectiveness. (Hiniker & Entin, 2006) Besides the higher connectivity created through the construction of broader band networks, the major information technologies that are indispensable for enabling NCW for a warfighting team are the Common Operational Picture (COP) coupled with a shared whiteboard for collaboration over the map of the battlespace. DISA's most advanced versions of these technologies are the **User Defined Operational Picture (UDOP),** as instantiated by NECC C2 Common Services with the **Lightweight Collaborative Whiteboard (LCW).** In addition, warfighter access to remote data base capabilities such as **SORTS (Blue Force Readiness)** data base and the improved **TMS/CWS (Red Force Tracker)** data base should contribute directly to the speed and quality of replanning, and hence also contribute to increased NCW combat effectiveness.

Does greater Speed of Command via improved speed and quality of replanning utilizing remote data bases by a distributed warfighting team enabled by a network in fact cause improved combat effectiveness? What are some of the causal mechanisms involved? The **purpose** of the experiment described here is to demonstrate and to analyze the differences in operational effectiveness between current warfare practices and NCW practices using the combined technologies of the UDOP with collaboration technology, and the remote data bases of SORTS and TMS/CWS while capturing quantitative measures of NCW parameters under controlled conditions. Here collaboration technology is instantiated through the LCW shared map planning capability with audio.

In addition, this experiment will serve as an early Operational Assessment in the **Test and Evaluation** of the combined Capability Modules of UDOP, SORTS, and TMS/CWS as contributors to the effectiveness of the Adaptive Planning Capability Definition Package which is expected to increase significantly the measures of the Key Performance Parameters of the Combat Loss Exchange Ratio and the Speed and Quality of Replanning in the combat mission threads played out by the participating warfighting teams here. (See DoD/DAU, 2003; TTCP GUIDEx, 2006)

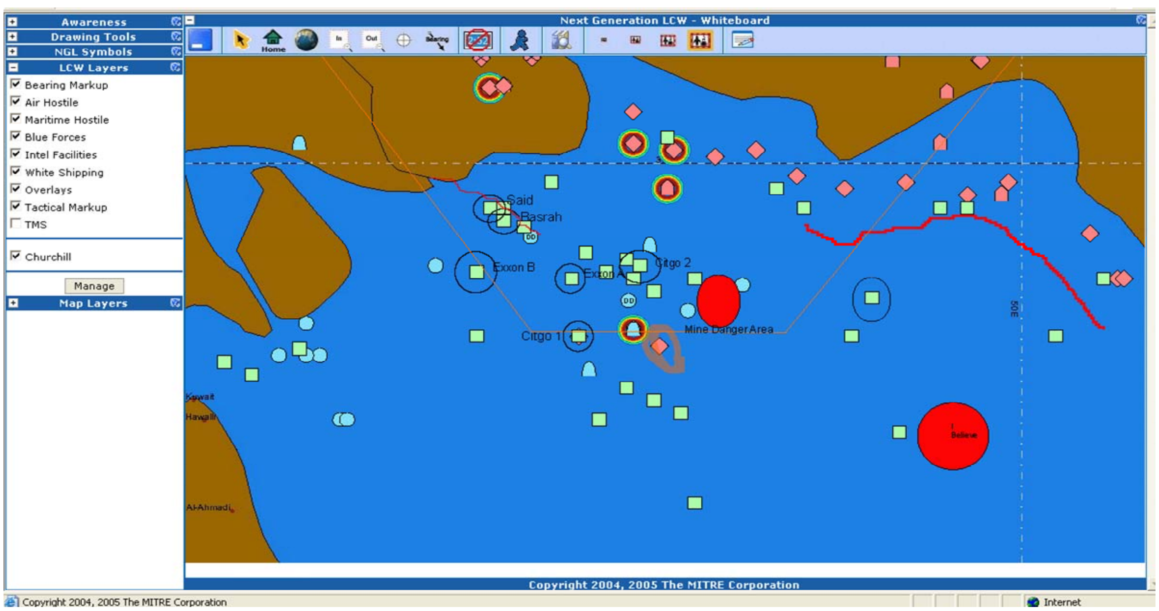
In the evolutionary development of C2 technology it is useful to benchmark progress
through the use of standard measures of performance and effectiveness. Thus use of the standard performance parameter of Situational Awareness was made in a 1990 experiment (Hiniker & Entin, 1990) and again in 2006 in an experiment with a similar scenario and set-up. The comparison of the results of these two experiments demonstrated noteworthy evolution in C2 capability for the warfighter over the intervening decade and a half (Hiniker & Entin, 2006). The baseline condition in the first experiment consisted in local tactical pictures located at the two ship captain posts and a big picture Gulf view located at the remote team leader's command post. This experiment showed significantly higher Situational Awareness by the warfighters in the COP prototype treatment condition. The later experiment used the COP condition as baseline and found comparable and significant improvements in Situational Awareness in the post-replanning phases of the experiment when warfighters employed the new collaborative UDOP technology. Such a comparison in the evolution of technological progress in C2 would be more difficult to draw without the use of standard measurements of performance parameters. In the current experiment, we examine the impact of these surviving C2 technologies coupled with new network enabled distributed intelligence and readiness databases, i.e. TMS/CWS; and SORTS, while focusing on the measurement of their contribution to effective adaptive planning by the warfighting teams.

Approach

The NECC Delta Experiment introduced above is another "true experiment" with controls examining the effectiveness of some new C2 technology, drawn from NECC, utilized by a distributed command team of joint warfighters collaborating and replanning over an IP Network with access to remote operational planning data bases while engaged in simulated combat scenarios compared to the effectiveness of warfighter performance employing current baseline condition technology. In the approach adopted here, variably equipped warfighting teams were experimentally created in a **controlled Human-In-The-Loop (HITL) experiment** utilizing the JTLS wargame simulator, and their performances were systematically related to combat outcome. (See TTCP GUIDEx, 2006) In the experiment each of four warfighting teams, each composed of an Air Force officer, a pair of Naval Tactical Action Officers (TAO) and an ashore higher level operational planner at CJTF with the authority to change Rules of Engagement (ROE) and provide additional blue forces, play out four battles composed of modified versions of a Persian Gulf air/sea counter-terrorist combat scenario, termed Operation Storm Petrel, crossed with two versions of information technology, the collaborative UDOP with associated distributed intelligence databases and the baseline COP/CHAT ensemble. The baseline technology is that currently in use by most of our forces for scenarios similar to ours.

The mission of the blue teams, including the two ship captains protecting two major and six minor oil platforms off Basrah in the Persian Gulf, was to identify and to prosecute advancing terrorist fast attack craft and pirated aircraft. In each scenario run, one of the Naval officers played the role of captain/TAO of the guided missile destroyer USS Winston S. Churchill with all its resources (e.g. guns, missiles, helicopter), the other Naval officer played the role of captain/TAO of the guided missile destroyer USS Mason with all its resources and the Air Force officer played the role of Air Operations Coordinator (AOC) – controlling all fixed wing blue aircraft in the simulation. A joint staff officer played the role of the ashore higher level operational planner at CJTF who provided changes to the readily available additional blue forces, assistance with changes to the team plan, and timely alerting and delivery of relevant intelligence over the net. Opposing these blue forces were a dozen terrorist fast attack craft, Boghammers, and two pirated Cessnas or two stolen MIG 29s under red control as played by a JTLS simulator operator. There were also two other blue ships, USS Arctic and USS Ardent, and dozens of neutral ships and commercial aircraft in the area. Each of the four slightly modified scenarios was divided into three time phases: TP1 consisting of Stage Setting and initial combat operations; TP2 consisting of Replanning triggered by a surprising new terrorist assault against oil platforms or US Naval ships, involving red fast attack craft or pirated aircraft, or an abrupt change in the ROEs from higher blue authority; and TP3 consisting of the End Game of the combat operation. The basic scenario is analogous to the Basrah terrorist incident of Spring 2004 as well as to Operation Praying Mantis of 1986.

DISA UDOP Screenshot of Scenario



NCW Metrics. For all four newly created four-man teams and for each time phase of all four trials, **Situational Awareness (SA)** is defined as the proportion of the crisis relevant, or mission critical, set of warfighting platforms, red, blue or neutral, correctly identified as important by the commander. (Hiniker & Entin, 1990; Hiniker, 2002; Perry et.al, 2004; Hiniker, 2005; Hiniker & Entin, 2006)) During the simulated combat operation, using the JTLS wargame simulator, the commander's realization of the situation, his Situational

Awareness, was obtained by his drawing on a map the platforms he deemed important at that time, i.e. by his personal Cognitive Operational Graphic (COG). The commander's proportion correct was then obtained by comparison with the platforms on the simulator's Ground Truth map at the same time. Greater overlap between the commander's COG and Ground Truth is indicative of greater Situational Awareness by the commander at the time. Greater overlap between the COGs of the team of three commanders is indicative of greater **Shared Situational Awareness (SSA**). (Hiniker, 2002; Perry et al, 2004; Hiniker & Entin, 2006) Thus these SA metrics take account of the fit for each mission relevant weapons platform between its psychological world cognition, its information world record and its physical world existence. Such COG measures, together with a set of additional measures including current Plan quality and teamwork were obtained by trained observers for all commanders at the end of each of the three phases of each of the four combat scenarios.

Planning quality (P), itself, was measured by summing, and then averaging for the team, the seven-point Likert scale observer evaluations of five items comprising the quality of performance of the stages of the OODA Loop planning cycle: observation, orientation, decisionmaking, execution, and overall planning and plan execution performance. (Hiniker & Entin, 2006)

Speed of Command (t_d) was measured by summing the team's time to size up the situation plus time to replan plus time to act plus time to complete the decision cycle with battle damage assessment and begin to review the new situation. (See Appendix) Each replanning cycle begins with a surprising new, unanticipated move by red or with a higher level ordered change in the blue ROEs. Thus Speed of Replanning, t_r , is the time taken within the new decision cycle between the team's newly sizing up the changed situation and the team's beginning the new course of action.

Finally, the **combat Effectiveness (E)** of the warfighting team for each time phase derives from the JTLS wargame simulator tally of the loss exchange ratio of warfighting platforms for the time phase, red losses/ red plus blue plus neutral losses. (Hiniker, 1991; Hiniker and Entin, 1992; Hiniker & Entin, 2006)

During the experiment all teams operated as “edge organizations” in that command was relatively decentralized, team member interactions were relatively unconstrained, and information was broadly distributed. What differentiated the teams was the technology they used. Four, four-man joint warfighting teams prosecuted the Operation Storm Petrel scenario during 16 counter-balanced trials conducted in late April/May 2007 as a Limited Objective Experiment (LOE) at the JFCOM Joint Systems Integration Command laboratory under two different **technology treatment conditions:**

- In the **C2 Baseline treatment condition**, all three military players shared the same GCCS COP view of the Gulf and communicated via CHAT, using the current intelligence product obtained under current time lines. This is the technology suite with which most of our players had years of operational experience.

- In the new **NCW treatment condition**, the airman received TMS/CWS track and intel data injects, and C2 common services tailored to air Community of Practice, the two sea captains received TMS/CWS track and intel data injects and C2 common services tailored to maritime Community of Practice, and the higher level planner at CJTF received all of these data plus access to the SORTS/Blue Force Readiness data base and all four warfighters jointly collaborated in combat using a common LCW with drawing functionality and with simulated VOIP and joined Operational Context with stated Commander’s Intent forming a common Community of Action. Here all communications for the distributed team, including Operation Storm Petrel web portal access, information searches, and simulator and operational data base updates, were conducted over an IP broadband wide area network.

A Complex Adaptive Systems (CAS) View of NCW and Experiment Hypotheses

It is useful to conceive of the warfighting team, either distributed or local, as a CAS. The collaborative UDOP with associated distributed intelligence data bases provide shared schema for the warfighting team, i.e. shared representations inside the warfighting team of the relevant external environment. (Hiniker, 2002) These shared representations or "schema" provide the CAS with descriptions, predictions, and prescriptions for effective interactions in the environment. (Gell-Mann, 1994; Gell-Mann, 1997) The UDOP represents the current situation; and the LCW permits shared graphic representation of future planned situations. The TMS/CWS data base provides up to date information on the location of red warfighting platforms; and the SORTS database provides information on the current readiness status of blue warfighting platforms, both local and global. Such informational schema, representing the relevant aspects of the situation and what to do about it, form the major portion of the relevant message traffic passed around the communications system, and taken together these messages constitute replicas of the state of the command decision process, itself. (See Girard, 1990) For the most part, in this "information world", observations and assessments come in and go up; plans and directives come down and go out.

The shared schema when internalized by human warfighters constitute shared mental models (Rouse and Morris, 1986), and should enable the warfighting team, conceived of as a unified CAS, to complete the group OODA (Observe-Orient-Decide-Act) Loop process more rapidly and effectively leading to greater combat effectiveness. UDOP schema should mainly aid SA; LCW schema should mainly aid Planning activities: and TMS/CWS, I3, and SORTS distributed data bases contribute to both sets of processes.

Since the informational schema are shared as mental models by human warfighters, their effectiveness is, of course, subject to the human constraints of bounded rationality, analogous to the channel capacity constraints on the speed of information transmission over a network: Performance impairing information overload can and does occur at both the psychological and informational levels of a socio-technical system. (Levis et al, 1987; Hiniker, 2002) At the "ground truth" level of the physical world, as well, human actors, sensors, weapons platforms, communications networks, and associated software and data bases can and do become impaired in the course of warfare.

Thus the interactions of the CAS with its environment entail both linear and non-linear relationships. Human information overload is an instance of a non-linear relationship in that a small positive change in informational workload near the crash threshold results in a very large degradation in performance. Most network interactions involving humans are not simple random network interactions; rather they usually involve "small world" nets including shortcuts or "scale free" nets including hubs and may, under certain conditions, exhibit non-linear "percolation effects" (Moffat and Atkinson, 2005) Here the focus will be upon the existence, rather than the form, of causal relationships between a warfighting team's use of shared schema and the consequent effectiveness of their operations in the battle space. (See Pearl, 2001) Several causal hypotheses regarding expected empirical relationships are proposed below.

Hypothesis 1. By facilitating the development of more accurate and more complete shared mental models, use of the collaborative UDOP with associated distributed data bases by a warfighting team causes significant improvement in their Situational Awareness (SA). (See Hiniker & Entin, 1990). This effect should be amplified in scenarios in which the assessment is highly uncertain, i.e. situations in which there are many ambiguous fast moving tracks of potential mission relevance. The tailored expert views afforded by UDOP coupled with the broader channel for team communication provided by LCW coupled with audio should help mitigate the information overload when compared with use of the baseline COP/CHAT technology. Access to the distributed data bases of TMS/CWS and SORTS should contribute to the accuracy of their Situational Awareness.

Hypothesis 2. By facilitating group consensus on the important and relevant weapons platforms in the situation, use of the collaborative UDOP with associated distributed data bases by a warfighting team causes significant improvement in Shared Situation Awareness (SSA) across the team..

Hypothesis 3. By facilitating group consensus, use of the collaborative UDOP with associated distributed data bases by a warfighting team increases the quality or desirability of their developed Plan (P).

Hypothesis 4. This, in turn, increases the synchronicity of the warfighting team's action (A), leading to greater Combat Effectiveness (E).

Hypothesis 5. Use of the collaborative UDOP with associated distributed data bases should increase the speed with which the warfighting team typically completes the OODA Loop (t_d), including the speed of replanning ,t_r , also leading to greater Combat Effectiveness (E). (See Appendix for measurement definitions of terms)

Results. The analysis of the results of hypothesis testing in this experiment utilizes the techniques of Analysis of Variance (ANOVA), following a within subjects design, to determine whether or not use of the collaborative UDOP with associated distributed data bases technology enabled the warfighting teams to perform significantly more effectively on the NCW performance metrics examined when compared to their use of the baseline technologies. Use of these quantitative performance metrics also permits one to estimate the values of the NCW parameters exhibited by the warfighting teams, under each of the treatment conditions. In addition to these objective performance measures, subjective evaluations by the participants of the two sets of technologies were also solicited and analyzed.

H1: *Use of the collaborative UDOP with associated distributed data bases by a warfighting team causes significant improvement in their situational awareness*. As shown in Figure 2 below,

Figure 2. Team Situational Awareness by Scenario Time Phases for Technology Treatment Conditions……..

Warfighter Opinion. The sixteen warfighters who participated in this experiment were experienced with use of the baseline technology. Nevertheless the majority of these experienced warfighters were quite receptive to the new NCW technology as indicated by their subjective opinions expressed on the JDCAT survey instrument. When asked "With regards to the plans that were generated
(using collaborative UDOP with associated distributed data bases) which best describes their quality?" **…………………**

Conclusions. In this controlled HITL experiment new NCW technology was introduced to a sixteen experienced warfighters in the form of a collaborative User Defined Operational Picture with associated distributed intelligence databases accessable over a wide area network as a possible improvement over their performance with current baseline technology…..

APPENDIX

Measurement Definitions for Collaborative UDOP Replanning Delta LOE

- **Situational Awareness (SA)** = Proportion of mission critical set of warfighting platforms correctly identified by a warfighter (Ground Truth cf. COG @ t_i)

- **Shared Situational Awareness (SSA)** = Proportion of overlap between pairs of COGs for complete warfighting team.

- **Plan Quality (P)** = Accuracy of knowledge of scheduled sequence of blue moves.

- **Speed of Command** ($\mathbf{t_d} = t_c + t_r + t_a + t_b$), where total speed of command is the sum of time to size up situation + time to plan + time to act + time to complete decision cycle with battle damage assessment

- **Combat Effectiveness (E)** = Loss/Exchange Ratio= red platform losses / (red + blue + neutral losses)

- **Subjective Opinion of Operational Value of Technology** = Participants' scoring on seven point Likert scale.

References.

(Alberts, Garstka & Stein, 2000) David Alberts, John Garstka and Fred Stein. *Network Centric Warfare: Developing and Leveraging Information Superiority*. DoD C4ISR Cooperative Research Program, 2000.

(DoD/DAU, 2003) Dept of Defense/Defense Acquisition University. *GLOSSARY: Defense Acquisition Acronyms and Terms*. Ft. Belvoir, VA: DAU Press, 2003.

(Gell-Mann, 1994) Murray Gell-Mann. *Complex Adaptive Systems* in G. Cowan, D. Pines and D. Meltzer (Eds.) *Complexity: Metaphors, Models and Reality. SFI Studies in the Sciences of Complexity, Proceedings, Vol. XIX, Addison-Wesley, 1994.*

(Gell-Mann, 1997) Murray Gell-Mann. *The Simple and the Complex* in David Alberts and Thomas Czerwinski *Complexity, Global Politics and National Security.* Washington, D.C.: National Defense University Press, 1997.

(Girard, 1990) Paul E. Girard. *Stochastic Conditional Object Oriented System Analysis.* Proceedings of the Joint Directors of Laboratories (JDL) Symposium on C2 Research, 1990.

(Hiniker, 1991) Paul J. Hiniker. *HEAT Experiments: Use of the Experimental Method to Evaluate the Effectiveness of HQ C2 Insertions*. Proceedings of the JDL Symposium on C2 Research. National Defense University, Washington, DC, 1991, pages 323-331..

(Hiniker, 2002) Paul J. Hiniker. *A Model of Command and Control Processes for JWARS: Test Results from Controlled Experiments and Simulation Runs.* Proceedings of the 7th International Command and Control Research and Technology Symposium, Quebec City, Canada, 2002)

(Hiniker, 2005) Paul J. Hiniker. *Estimating Situational Awareness Parameters for NCW from Experiments.* Proceedings of the 10th International Command & Control Research and Technology Symposium. McLean, VA, June 2005.

(Hiniker and Entin, 1990) Paul J. Hiniker and Elliot E. Entin. *The Effects of Shared Battle Graphics on Team Performance in Crisis Situations.* Proceedings of the JDL Symposium on C2 Research. Naval Postgraduate School, Monterey, CA, 1990

(Hiniker and Entin, 1992) Paul J. Hiniker and Elliot E. Entin. *Examining Cognitive Processes in Command Crisis: New HEAT Experiments on Shared Battle Graphics and Time-tagging.* Proceedings of the JDL Symposium on C2 Research. Naval Postgraduate School, Monterey, CA, 1992.

(Hiniker and Entin, 2006) Paul J. Hiniker and Elliot E. Entin. *"Assessing the Operational Impact of Network Centric Technology, Collaborative User Defined Operational Picture:*

A Controlled Experiment with Warfighters, Proceedings of 11th ICCRTS, Cambridge, UK, 2006.

(Levis, et al, 1987) Alex Levis, A. Louvet, and J. Casey, *Experimental Investigation of the Bounded Rationality Constraint,* Proceedings of the JDL BRG C2 Research Symposium, National Defense University, July 1987.

(Moffat and Atkinson, 2005) James Moffat and Simon R. Atkinson, *The Agile Oranization.* Washington, D.C.: CCRP Publication Series, 2005.

(Pearl, 2001) Judea Pearl. *Causality.* Cambridge, UK: Cambridge University Press, 2001.

(Perry et al, 2004) Walter Perry, David Signori and John Boon. *Exploring Information Superiority: A Methodology for Measuring the Quality of Information and Its Impact on Shared Awareness.* RAND, 2004.

(Rouse and Morris, 1986) W.B. Rouse and N. M. Morris. On Looking into the Black Box: Prospects and Limits in the Search for Mental Models. *Psychological Bulletin,* 100, 1986, pp. 349-363.

(TTCP, 2006) The Technical Cooperation Program (AUSCANNZUKUS*). GUIDEx (Guide for Understanding and Implementing Defense Experimentation), See esp. pp. 234-250.* Ottawa: Canadian Forces Experimentation Center, Feb 2006.